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Effects of two species of tropical earthworms (Oligochaeta: Eudrilidae) on the size distribution of aggregates in an African soil

BY

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Synopsis: Increased proportions of large aggregates occur in sieved soils where eudrilid earthworms are present. Aggregation in these soils is considered to result from the effects of casting plus additional components due to colloids, the activity of microorganisms and binding of fresh casts to non-ingested soils.

Keywords: Earthworms, aggregate size distribution, soil structure, soil aggregation, African savannas, Eudrilidae, *Panicum maximum*.

INTRODUCTION

It is now well established that earthworms play an important role in soil dynamics through the formation of stable macroaggregates and development of the soil profile (ROGAAR & BOSWINKEL, 1978; SPRINGETT, 1983; AINA, 1984; EDWARDS, 1985; LEE, 1985; SHAW & PAWLUK, 1986; LAVELLE, 1988). They would thus be expected to have beneficial effects on soil fertility.

At Lamto (Côte d'Ivoire), mean earthworm biomass in shrub savannas is *ca.* 500 kg of fresh weight.ha^{-1} and populations may ingest up to 1 000-1 250 tons of dry soil annually. The high rate of soil passage through earthworm populations is considered responsible for the existence of a coarse macroaggregate structure in the upper 15 cm of the soil profile (LAVELLE, 1978).

Earthworm communities comprise 9 species of different sizes and ecological strategies. Three types of casts may be distinguished:

– casts of detritivore species which are deposited mainly at the soil surface and contain less than 1% of grass and leaf litter; their production in 1972 was estimated at 35 to 126 tons.ha^{-1}, 2 to 7% is excreted at the soil surface;

– casts of large endogeic species, rounded and several mm to a few cm in length; only 0.5 to 1.3% of these casts are deposited at the soil surface;

– casts of small filiform Eudrilidae, endogeic species, comprising a fragile accumulation of small granules (from 1 to 2 mm long). *Ca.* 85% of these casts are deposited in the soil. The rest are deposited at the soil surface where they are easily dispersed by running water and might be a factor in soil creep (Nye, 1955).

The aim of this study was to evaluate the capacity of eudrilid earthworms to contribute to the aggregation of a destructured savanna soil in the presence of the tropical perennial grass, *Panicum maximum* Jacq.

I. – MATERIALS AND METHODS

A) Study site

The field work was conducted between April and mid-June 1987 at the Station d'Écologie Tropicale de Lamto in Côte d'Ivoire (5°02'W, 6°13'N, elevation 105 m). Despite a sandy texture and a low clay (kaolinite) content (Tab. I), this soil (a Ferralsol, F.A.O. classification) has a resistant crumb structure in the upper 15 cm of soil profile. *Ca.* 50% of soil is present as aggregates > 2.0 mm.

Tab. I. – **Selected physical and chemical characteristics of the 0-10 cm horizon of Lamto's tropical ferruginous soil** (Riou, 1974).

Clay 0-2 µ	7.5 %
Fine silt 2-20 µ	5.8%
Coarse silt 20-50 µ	8.2%
Fine sand 50-200 µ	29.4%
Coarse sand > 200 µ	46.0%
Soil Organic Matter %	2.0
C % (Anne)	1.09
N % (Kjeldahl)	0.076
C/N	14.3
P_2O_5 total % (Olsen)	0.18
Fe total %	0.63
Ca meq/100 g	2.34
Mg meq/100 g	0.69
K meq/100 g	0.12
Na meq/100 g	0.05
Sum of cations	3.2
Saturation Indice V %	80.0
CEC meq/100 g (Metson)	4.0
pH	6.0

B) Eudrilidae earthworms

Two dominant species of Eudrilidae, *Chuniodrilus zielae* (Omodeo) and *Stuhlmannia porifera* (Omodeo et Vaillaud) were used in the experiments. They are small, filiform earthworms (3-7 cm length, 0.5-2 mm diameter) which can only be distinguished at the adult stage when external sexual organs become visible. *C. zielae* is more abundant in shrub savannas and is, on average, distributed closer to the soil surface than *S. porifera*. They are both geophagous, polyhumic endogeic species. Surface casts are accumulations of small granules, 80% of which have diameters between 1-2 mm. In 1972, eudrilid earthworms ingested 116-173 kg dry soil.ha^{-1} depending on the savanna type. Approximately 85% of the soil was ingested in the upper 20 cm of soil (LAVELLE, 1978) and about 15% was cast at the soil surface.

C) Experimentation

The soil used for the experiment was taken from a depth of 0-10 cm at a single location in a shrub savanna. After collection, the soil was carefully mixed and then destructured by passing it through a 2.0 mm sieve. The air-dried equivalent of approximately 6 800 g of oven-dried (105°C) soil was then weighed into plastic buckets which had been previously fitted with drainage holes covered with a fine mesh. The buckets were allocated randomly to treatments, brought to field capacity and a number of seeds planted in each. These were later thinned to three seedlings per container.

The containers were laid out in a simple randomized blocks design with the control treatment (without earthworms) replicated five times and the remaining treatments three times. In order to avoid overheating the contents, the containers were buried in the soil so that the soil surface was level with the contents of the containers. An air space was left below the containers to allow free drainage and to check on the possible entry or egress of roots.

Biomasses of 0.5 and 1.0 g of live adult earthworms were added to the appropriate containers within three days of planting the grass seeds. During the course of the experiment, the containers were watered regularly.

The seeds of *P. maximum* were planted on the 1st of April 1987, the seedlings started to emerge 5 days later and plants were harvested on the 17-18th of June, after 79 days of growth. After harvesting the above-ground parts of the plants, the soil was removed from the containers, broken into large fragments (*ca.* 800 cm^3) and air-dried to a moisture content of approximately 5-6%. Aggregates were separated by dropping the air-dried fragments from a constant height of 1.5 m onto a hard surface. The aggregates were further air-dried, dry-sieved into the diameter classes listed in Table II and the fractions weighed.

D) Statistical treatments

The data for each size class of aggregates were subjected to a nested, or split-plot analysis of variance. The presence or absence of the eudrilid earthworms and their masses added to the containers were the main effects and depth in the container was the nesting factor. The control treatment (no earthworms added) was replicated five times although only the data for the first three blocks were used in the statistical analyses.

In six size classes, the data were transformed prior to analysis in order to equalize the error variance. Outlying observations were removed from the data set from some of the smaller size classes. The significances of the differences between means for all size classes at depths in the container were tested using Least Significant Differences (COCHRAN & COX, 1957).

II. – RESULTS

The analysis of variance showed a significant ($P < 0.05$) effect of adding earthworms to the containers on the proportions of aggregates in all except two size classes (0.4-0.5 mm and 0.63-1.0 mm) (Tab. II). In aggregates between 0.4 and 0.5 mm, no significant treatment or depth effects were noted. In those from 0.63 to 1.0 mm and 1.0 to 2.0 mm, small but significant ($P < 0.01$) reductions in the proportions of aggregates were noted in the top 5 cm of the soil.

Tab. II. — **Analysis of variance of the size distribution of aggregates in relation to the addition of eudrilid earthworms to an initially de-structured soil supporting *Panicum maximum*.** Significance of the presence of eudrilid earthworms and the interactions with depth in the container, ($+ = P < 0.05$; $++ = P < 0.01$; $+++ = P < 0.001$). Transformation type: a = angular transformation; $b = \log_e + 0.5$ transformation; $c = (\text{data})^{0.333}$ transformation.

Aggregate diameter class (mm)	Presence/ absence Eudrilidae	Depth	Depth/ Eudrilidae	Transformation type
0.0 - 0.250	+(< 0.025)	ns	ns	–
0.250 - 0.315	+(< 0.025)	ns	+ + +	–
0.315 - 0.40	+ +	ns	ns	–
0.40 - 0.50	ns	ns	ns	–
0.50 - 0.63	ns	+ +	+(< 0.025)	a
0.63 - 1.0	ns	+ +	ns	a
1.0 - 2.0	ns	+ + +	+(< 0.025)	b
2.0 - 5.0	+ + +	ns	ns	–
5.0 - 6.3	+ + +	ns	+(< 0.025)	c
6.3 - 10.0	+(< 0.025)	ns	+ +	–
> 10.0	ns	ns	+ +	b
2.0 - 10.0	+ + +	ns	+(< 0.025)	–
> 2.0	+	ns	+ + +	c

In the three classes 0.0 to 0.25 mm, 0.315 to 0.4 mm and 2.0 to 5.0 mm, simple effects of the presence of earthworms were found. Apart from these classes, there were significant ($P < 0.05$) interactions between the presence of earthworms and depth in the container.

In only one class (0.5 to 0.63 mm), was there a significant ($P < 0.05$) effect of the mass of earthworms added. This was confined to the surface 5 cm where there was a significant ($P < 0.05$) difference between the control and 1.0 g earthworm treatments, but not between the control and the 0.5 g treatment (Tab. III).

There was considerable correlation between data from the different aggregate size classes. Most of the classes greater than 2.0 mm were positively correlated with each other and negatively with those less than 2.0 mm.

Figure 1 presents the proportions of the total soil mass found as aggregates in the combined size classes < 0.4 mm, 0.4-2.0 mm and > 2.0 mm in relation to the biomass of eudrilid earthworms added and depth in the container. In the absence of earthworms a little aggregation occurs which is more important in depth than in the top 5 cm of soil (respectively 17.1% and 10.5% of soil as aggregates > 2.0 mm). Treatments with earthworms present a more important aggregation

TAB. III. – **Means (μ), standard deviations (σ) and levels of significance of the main effects (presence or absence and mass of eartworms added) for a range of aggregate size classes from containers in wich *Panicum maximum* was grown with and without eudrilid earthworms.** * = at this depth there was a significant ($P < 0.05$) difference in the proportion of aggregates between the treatments where no eudrilids were added and where 1.0 g was added.

Aggregate size class (mm)	Depth in container (cm)	Eudrilidae present		Eudrilidae absent		Significance of difference
		μ	σ	μ	σ	
0.0 - 0.25	all	16.7	1.9	19.5	2.6	< 0.05
0.25 - 0.315	0-5	4.6	0.5	6.0	0.9	< 0.05
	5-10	4.9	0.6	5.9	0.7	ns
	10-15	5.2	0.4	4.9	1.2	ns
0.315 - 0.40	all	13.8	1.7	16.6	2.2	< 0.01
0.40 - 0.50	all	8.4	1.4	9.7	1.3	ns
0.50 - 0.63	0-5	8.6	1.4	11.8	2.1	*
	5-10	11.1	2.6	10.8	1.3	ns
	10-15	9.6	1.0	10.2	1.8	ns
0.63 - 1.00	0-5	14.2	1.1	15.1	0.8	ns
	5-10	16.5	1.8	16.0	0.7	ns
	10-15	16.5	3.3	14.9	1.0	ns
1.00 - 2.00	0-5	8.4	2.8	9.3	1.8	ns
	5-10	9.0	2.1	8.9	1.6	ns
	10-15	9.6	2.9	9.5	2.2	ns
2.00 - 5.00	all	6.0	1.5	2.1	1.0	< 0.001
5.00 - 6.30	0-5	2.1	0.7	0.6	0.3	< 0.001
	5-10	1.4	0.4	0.5	0.2	< 0.01
	10-15	1.6	0.2	0.9	0.3	< 0.05
6.30 - 10.0	0-5	8.2	1.6	2.9	1.9	< 0.01
	5-10	6.2	1.4	2.9	2.0	< 0.05
	10-15	5.1	1.7	4.9	2.0	ns
> 10.0	0-5	9.3	2.9	5.2	3.2	ns
	5-10	7.0	2.8	6.3	3.9	ns
	10-15	6.0	2.8	8.7	3.9	ns
Σ (2.00 - 10.0)	0-5	17.1	3.0	5.3	3.2	< 0.001
	5-10	12.8	2.7	5.1	3.1	< 0.01
	10-15	13.0	2.4	8.4	3.2	ns
Σ (> 2.00)	0-5	26.3	5.1	10.5	6.0	< 0.05
	5-10	19.8	3.1	11.5	5.8	ns
	10-15	19.0	4.1	17.1	7.0	ns

and the percentages of aggregates > 2.0 mm are higher in the upper 5 cm than in the 10-15 cm layer (respectively 28.4% and 19.7% in the treatment with 0.5 g of earthworm).

In depth the differences observed between treatments with earthworms and treatments without earthworms are only significant in four size classes while in the top 5 cm these differences are significant in seven size classes (Tab. III).

Except for the 0.5-0.63 mm size class (0-5 cm depth), there were no significant differences in levels of aggregation between the 0.5 g treatment and 1.0 g treatment

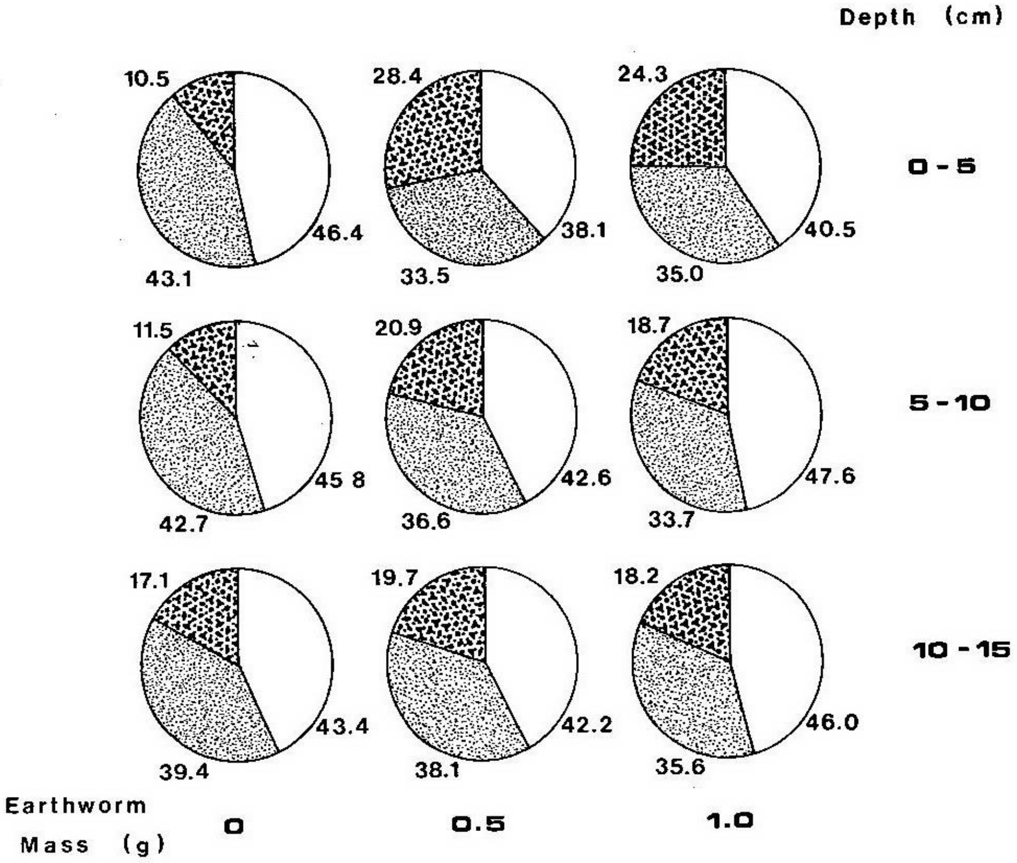

FIG. 1. – Spatial evolution of the size distribution of aggregate classes after action of Eudrilidae and in treatment without earthworms, and percentages of these aggregates size classes (white = aggregates < 0.4 mm; grey = aggregates 0.4-2.0 mm; black = aggregates > 2.0 mm).

in any of the size classes. However, the amount of soil aggregated in the 0.5 g biomass treatment was greater than that in the 1.0 g treatment.

III. – DISCUSSION

Earthworm biomasses at the end of experiment were two to three times greater than at the beginning.

Soil ingestion during the experiment was estimated using the experimental results of LAVELLE (1978). In optimal environmental conditions (pF 2.5, 27°C), individuals weighing on average 0.150 g ingest 0.600 g of dry soil daily. The total amounts of ingested soil at the end of experiment (80 days) were thus estimated at 320 g for 1 g Eudrilidae and 160 g for 0.5 g. These estimates of soil passed through earthworm guts are compared with the corresponding amounts of aggregated soil (Tab. IV).

TAB. IV. — **Comparison between aggregated soil and estimated soil ingested by eudrilid earthworms.**

	A = aggregated soil (g)	I = ingested soil (g)	D = A − I (g)
Control	867	0	867
0.5 g Eudrilidae	1 592	160 (10%)	1 432 (90%)
1.0 g Eudrilidae	1 407	320 (23%)	1 087 (77%)

In 1.0 g treatment, the large population of earthworms (4 times greater than the natural biomass of Eudrilidae but still half the overall average earthworm biomass) may be responsible for the low rate of soil ingestion by earthworms (negative density effect).

Without earthworms, aggregation (13.5% of aggregates > 2 mm) may be due to microbial activity and/or clays and colloids. In the presence of earthworms, more soil is aggregated than that estimated to have been ingested and thus, at least part of the aggregation observed can not be explained only by soil ingestion. Fresh casts may be bound to non-ingested soil to form large aggregates. This would explain the larger size of soil aggregates than the size of casts produced by Eudrilidae which are made of 1-2 mm spherical granules. That would explain the highly significant differences between treatments with earthworms and treatment without worms in size classes between 2.0 and 10.0 mm.

The presence of eudrilid earthworms appears to have increased the proportion of macroaggregates in soil. This aggregation was mainly apparent near the soil surface (0-10 cm) and considered to be due to several phenomena:

— casting of soil ingested by earthworms although this only accounts for a small part of total aggregated soil (10% for 0.5 g Eudrilidae and 23% for 1.0 g Eudrilidae);

— binding of particles by colloids produced by the worms (cutaneous mucus) or by microorganisms (fungal hyphae);

— binding of fresh casts to non-ingested soil.

IV. — CONCLUSION

In the granitic, sandy soils of Lamto, the numerically-dominant eudrilid earthworms contribute substantially to total aggregation. In the sieved soil used, their presence results in aggregates ranging in size from 2.0 to 10.0 mm, particularly near the soil surface. In contrast, aggregates formed in the same horizon by the larger species *Millsonia anomala* are predominantly greater than 10.0 mm (BLANCHART *et al.*, in preparation). Over a period of 79 days, the roots of the perennial grass *P. maximum* had no discernible effect on the production of aggregates.

Irrespective of earthworm size, the presence of these animals leads to increased soil aggregation. This may occur directly through cast production, by the stimulated growth of fungal hyphae in and from these casts or by the bounding of fresh casts to non-ingested soil.

It is concluded that earthworm activity in the Lamto soils is largely responsible for its compact, macro-aggregate structure. Small filiform eudrilid earthworms contribute to the formation of medium-size aggregates while the bigger species *M. anomala* forms correspondingly-larger aggregates. Future studies should aim to elucidate the interactions that occur between these earthworms in relation to their effects on the dynamics of aggregation.

Summary

This experimental study assessed the effects of two eudrilid earthworms on the aggregation of a 2 mm-sieved tropical ferruginous soil in the presence of a tropical grass (*Panicum maximum*).

Three treatments were imposed: no earthworms (control), 0.5 g (live biomass) and 1.0 g of earthworms per container.

After 79 days, the size distribution of aggregates was measured and the quantity of aggregated soil (aggregates > 2 mm) was compared with the estimated mass of soil ingested by earthworms.

In the presence of earthworms, aggregation was notably increased near the soil surface and reached 20.7% of total soil mass with 1.0 g of earthworms and 23.4% with 0.5 g of earthworms. Estimated amounts of ingested soil accounted for only a proportion of total aggregation. The increased aggregation found may be due to microbial activity, to colloids and to binding of freshly excreted casts to non-ingested soil. Aggregation in the control (13% of total soil mass) may have been due to a combination of microbial activity and colloids.

Résumé

Effets de deux espèces de vers de terre tropicaux (Oligochètes : Eudrilidae) sur la distribution par taille des agrégats dans un sol africain

Cette étude expérimentale tend à appréhender les effets de deux vers de terre de la famille des Eudrilidae sur l'agrégation d'un sol ferrugineux tropical tamisé à 2 mm en présence d'une graminée tropicale (*Panicum maximum*).

Trois traitements sont considérés : pas de vers (Témoin), 0,5 g de vers par seau et 1,0 g de vers par seau.

Au bout de 79 jours, la distribution des classes d'agrégats est mesurée et la quantité de terre agrégée (agrégats > 2 mm) est comparée à la quantité de terre ingérée par les vers.

Une agrégation se produit dans les témoins (13 % du poids de sol total) due certainement à l'activité microbiologique et/ou à des colloïdes du sol. En présence de vers, l'agrégation, plus importante, est surtout nette en surface et atteint 20,7 % du poids de sol total avec 1,0 g de vers par seau et 23,4 % avec 0,5 g de vers. Les quantités estimées de sol ingéré ne rendent compte que d'une partie de l'agrégation. Le maximum de l'agrégation est dû à l'activité microbiologique, aux colloïdes du sol et peut-être à la liaison des turricules fraîchement rejetés avec de la terre non ingérée.

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